Novel Acoustic Scattering Processes for Target Discrimination

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LONG TERM GOALS

This is part of the Shallow-Water Autonomous Mine Sensing Initiative (SWAMSI) to improve the reliability of acoustic methods using a wide frequency range and scattering data not necessarily limited to monostatic signatures.

OBJECTIVES

The objective of this grant is to examine issues supportive of the SWAMSI team effort by improving the understanding of acoustic scattering processes relevant to MCM and the shallow water environment. An example of an issue being investigated at Washington State University is the scattering of sound by a plastic truncated cone. The cone material and shape were selected to be relevant to high frequency signatures of certain explosive-filled mines. Other objectives involved improved understanding and modeling of scattering mechanisms that are broader in scope and are outlined below.

APPROACH

A multifaceted research approach appears to be advisable because some acoustic strategies may not *always* be applicable and different strategies may require widely different *amounts of time* to acquire the needed data for a given potential mine field. Consequently it appeared to Marston that the SWAMSI program should retain research components that support both *low frequency* and *high frequency* sonar technologies. It would be potentially useful to understand which features of the scattering are important for discriminating between live (explosive-filled) targets and decoy targets containing other materials. Commonly used explosives have some similarity to certain solid plastics in their acoustic properties: (1) both materials have longitudinal wave speeds greater than the speed of sound in sea water, but less than rocks, cement, or metals: (2) in many cases both materials have shear wave velocities *less than* the speed of sound in sea water.

The approach has approximately seven activities. Four of these activities relate mostly to laboratory based investigations, three of which concern potential applications of high frequency sonar systems. These three activities will be described first.

(1) Scattering by a truncated cone: In mathematical terminology a bluntly truncated cone is known as a frustum of a cone. In one target of interest, the explosive has this approximate shape. Our approach was to machine a frustum of a cone from a polystyrene-based material. The shape corresponded to the

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14. ABSTRACT
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15. SUBJECT TERMS

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target of interest, but reduced in size so that scattering measurements could be carried out in a 7000-gallon facility at scaled frequencies. The measurements were exploratory to determine if there were obvious high frequency signatures sensitive to the material properties of the target. This research is being carried out by a PhD. candidate: K. Baik. The PI has been involved in previous work on scattering by plastic targets [1-3].

(2) Scattering by a plastic circular disk: As a consequence of the complexity found in the plastic cone measurements, for comparison a plastic circular disk was fabricated of the same material and having the same thickness and average radius as the cone. Backscattering measurements were obtained as a function of aspect angle.

(3) Scattering by a partially exposed cylinder: When a metallic target is only partially exposed to sound in water because the target is either partially buried or partially submerged, there is a significant problem when applying elementary ray methods to understand and predict the scattering. The difficulty is that, depending on the degree of exposure to sound, there may be no specular points on the target where sound is reflected from the source to the receiver. Fresnel approximations and Fresnel zone concepts may be used, however there is some indication that these will break down in the frequency range of interest [4]. The approach taken here was to experimentally test the applicability of the Kirchhoff approximation for a situation where the dependence of the scattering on the target exposure could be approximated by an integral that could be evaluated by analytical means. The strategy is that if the method is successful, the approach could be generalized to other targets using numerical methods.

(4) OASES calculations: In secondary support of this project, the ability to apply fast-field computational methods based on the OASES algorithm will be helpful. With the partial summer-support of this grant Professor Scot F. Morse (Western Oregon University) has applied the publicly released version of OASES to computations of interest. The emphasis has been on a geometry relevant to the interpretation of wavefields measured with the support of ONR grant N000140310585 concerning evanescent acoustic waves.

(5) Computational tests relevant to ray methods for the modeling of buried targets: While this has not been a major part of the effort, certain computational tests were carried out to explore when ray methods could be easily corrected for the case of buried targets in absorbing media. Specifically it would be helpful to determine if ray methods may be used when the attenuation of sound in the surrounding media (e.g. sediment) is significant over the dimensions of the target. When is it viable to modify ray theory by introducing local ray attenuation, determined by the path length of different rays in the sediment? To examine this problem a computational benchmark is being investigated: the scattering by an elastic sphere surrounded by a fluid having intrinsic attenuation.

(6) Target fabrication for the 2004 Sediment Acoustics Experiment (SAX-04): Some resources for this grant were used to design and fabricate four small targets for deployment in SAX-04. These targets consisted of 3.8 cm diameter stainless-steel cylindrical shells. It turns out that one of these cylinders was perhaps one of the smallest target visible in SAX-04 SAS measurements.

(7) Participation in the analysis of SAX-04 data and visit to NSWC: A small amount of resources was used to facilitate Marston's participation in the analysis of SAX-04 SAS data at APL-UW during spring 2005. Results of that project will be separately represented by K. L. Williams (APL-UW). In

addition this grant partially facilitated a brief visit by Marston to NSWC (Panama City, Fl.) to discuss MCM topics of mutual interest.

WORK COMPLETED

In addition to the progress outlined below in the Results section, the following completed items are noteworthy. Some results of Marston's earlier ONR-OAS funded research on caustics were published [5]. A second manuscript on that research was peer-reviewed and accepted for publication in JASA [6]. An overview of our approach to ONR supported scattering research was prepared for the meeting "Boundary influences in high frequency, shallow water acoustics" [7] and a related overview was presented at an ASA meeting [8]. During the summer of 2005 most of the components were procured for a rail system for laboratory-based bistatic scattering measurements and SAS data acquisition in the 7000 gallon tank. The components are yet to be installed.

RESULTS

The principal experimental progress has been on activities (1) - (3) listed in the Approach section.

(1) Scattering by a truncated cone: The target fabricated from a polystyrene related plastic had the following properties: thickness = 18 mm, base diameter = 121 mm, upper diameter = 95 mm. Backscattering of tone bursts by a cone suspended in water was recorded as a function of tilt angle for various frequencies from 190 to 400 kHz. The tilt angle γ was the angle between the incident wave vector and the perpendicular on the small flat end of the cone. Consequently $\gamma = 0$ is for sound directly incident on the top (the small part) of the cone. Consider, for example, the backscattering of a 6 cycle tone-burst at 400 kHz shown in Figure 1. (For an actual mine the scaled sonar frequency is more than a factor of 10 smaller.) Figure 1 shows the backscattering (log scale with 60 dB dynamic range) as a function of tilt angle (vertical axis) and time (horizontal axis). As a consequence of the complexity present in Fig. 1, measurements were also obtained for γ of 90 to 180 deg. where $\gamma = 180$ deg. corresponds to a target in reversed orientation (an up-side-down truncated cone). Relative arrival times for various backscattering enhancement mechanisms were calculated from ray theory. By comparing those predictions with the γ dependence for the normal and reversed orientation it was possible to verify several backscattering enhancement mechanisms associated with transmitted longitudinal and shear waves within the plastic given by ray theory. Features associated with transmitted longitudinal waves are likely to remain present even if the attenuation of shear waves becomes larger than in the case for the specific plastic used here. It is important to note that those rays mainly probe the outer part of the cone. Several of the enhancements are significantly larger than the backscattering associated with simple specular reflection from the side of the cone. Selected preliminary aspects of these results were included in [9].

(2) Scattering by a plastic circular disk: The observed time dependence of the backscattering on the tilt angle has several important differences from the truncated cone case even though the target material is the same and the target volume is approximately the same. To gain insight into this case, the first detailed computations were carried out of the antisymmetric a_0, symmetric s_0 Lamb wave dispersion relations for a plastic plate with water on both sides in the relevant frequency range. In addition, calculations were carried out of the dispersion relation of the Rayleigh wave on a plastic half-space loaded by water. As previously found for a different plastic by Hefner & Marston [1] the Rayleigh wave is subsonic relative to water. For a flat plate such a wave does not leak acoustical energy except

at the edges of the plate. Some of the measured enhancements have been identified with subsonic guided waves coupled to the sound field at the edges of the plate. Supersonic enhancements for a stiffer plate were previously identified by Hefner & Marston [10].

(3) Scattering by a partially exposed cylinder: The specific experimental test and theory were for the case of a steel cylinder being lowered through the air-water interface of the water tank. The theory was formulated in such a way that the singularities associated with transitions in the number of rays present (as the cylinder is lowered) were not present in the Kirchhoff approximation. Time-domain gating was used to extract only the specular part of the backscattering. The grazing angle was set to 30 degrees and typical frequencies and k*a* values were 140 kHz and 11 where *a* denotes the cylinder radius and k denotes the acoustic wavenumber. Since the water surface is flat, significant backscattering will not occur until the cylinder contacts the surface. As the cylinder is lowered, more of the cylinder's surface is illuminated and the backscattering tends to increase. The initial increase is associated with paths that become the simple specular reflection. Eventually other paths become significant that involve reflections from the cylinder and the flat-water surface. These can interfere destructively to give a complicated dependence on the cylinder depth, which is generally predicted by our theory [11]. The experiments confirm the applicability of the Kirchhoff approximation for the reflection part of the scattering by a partially exposed cylinder. The theory also shows that the dependence of the interference features on the exposure of the target depends on the boundary conditions assumed at the plate surface. The Kirchhoff approximation was also compared with the exact solution for backscattering from a rigid cylinder that breaks half-way through a plane with a soft boundary.

Other areas: There has been progress. Contact Marston if information is needed.

IMPACT/APPLICATIONS

Our discovery of various non-specular scattering enhancements for a plastic truncated cone suggests that high-frequency acoustic signatures could be used to distinguish between certain explosive-filled and decoy mines, provided the acoustic information is *carefully selected*. The success of the Kirchhoff approximation for modeling the reflection part of the scattering at grazing incidence for a partially exposed cylinder suggests that the evaluation of the Kirchhoff approximation using numerical methods for other target shapes would give results helpful to some imaging applications.

The research supported by this grant appears to be significantly different from recent scattering research in Europe, reviewed by Marston for ONR Global in [12].

RELATED PROJECTS

Our application of OASES-based computations to the interpretation of evanescent acoustic wavefields measured with the support of ONR grant N000140310585 will be presented at the October 2005 ASA meeting [13].

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B. R. Dzikowicz & P. L. Marston, "Doubly-focused backscattering from finite targets in an Airy caustic formed by a curved reflecting surface," J. Acoust. Soc. Am. (accepted).

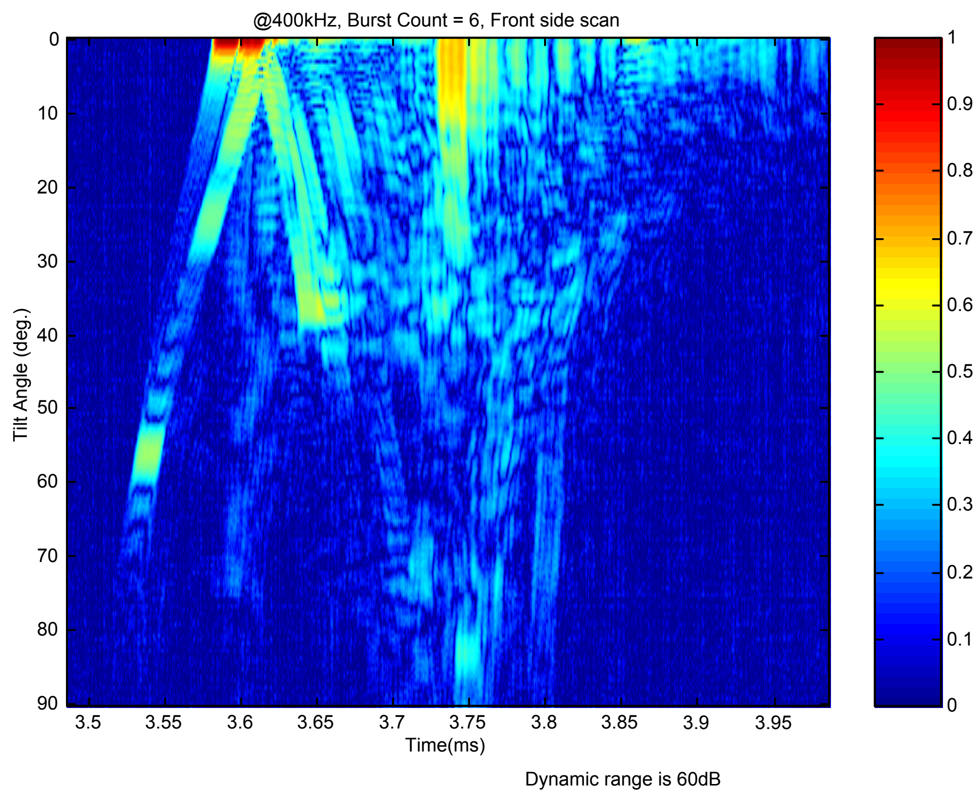

Figure 1. Measured backscattering amplitude for a plastic truncated cone (as indicated by the color scale on the right), as a function of tilt angle and time. A vanishing tilt indicates the wave is incident on the small flat side of the cone. The incident wave is a 6-cycle 400 kHz tone burst. The dark red region in the upper left is the specular reflection from the flat top of the cone. The dark blue level (indicated as level zero on the scale on the right) indicates the signal is at least 60 dB below the strongest echo in this scan. The specular reflection from the side is the early echo near 55 degrees. Ray models and other tests indicate that longitudinal waves transmitted through small sections of the plastic near edges contribute significantly to the front-edge enhancement near 24 degrees and to the rear-edge enhancement near 31 degrees. Shear waves and waves guided by the plastic also cause some of the enhancements. The pattern changes significantly from the one shown if the truncated cone is flipped over so that the lager of the flat sides is closest to the source. The changes in the pattern are consistent with ray theory predictions.